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Augmented Reality-Assisted Project-Based Learning: Enhancing Mathematical Problem-Solving Skills and Motivation in Junior High School Students

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Abstract

This study examined the improvement of mathematical problem-solving skills and learning motivation among students taught using the Project-Based Learning (PjBL) model assisted by Augmented Reality (AR). It also investigated the interaction between the learning model and students' ability levels to enhance these skills and motivation. A quantitative approach was employed using a pre-test and post-test control group design. The study population consisted of eighth-grade students from a public junior high school in Banda Aceh, Indonesia, with a randomly selected sample of four classes—two experimental and two control groups. Research instruments included mathematical problem-solving tests and student motivation questionnaires. Data were analyzed using one-way and two-way ANOVA. Findings indicate that students taught with the AR-assisted PjBL model demonstrated greater problem-solving skills and motivation improvements than those taught with the PjBL model without AR. Additionally, no significant interaction was found between the learning model and students' ability levels to influence these outcomes. These results suggest that the AR-assisted PjBL model is effective for students of all ability levels and should be further implemented across different mathematical topics.

Introduction

The purpose of problem-solving is to enable students to address real-life challenges (Phonapichat et al., 2014;Albay, 2019). The importance of problem-solving is emphasized by the NCTM, (2000), stating that (1) problem-solving is a fundamental aspect of mathematics; (2) mathematics is applicable in various contexts; (3) mathematical problems inherently provide motivation; (4) problem-solving can be engaging and enjoyable; and (5) it helps students develop essential problem-solving techniques. Additionally, problem-solving skills are considered crucial at all levels of education, as they support the development of students' cognitive abilities during the learning process.

However, students' problem-solving skills remain a significant concern (Samo, 2017; Nidya et al., 2015; Jerizon et al., 2018). Many students struggle with problem-solving, and some cannot solve mathematical problems effectively (Putra et al., 2018). Moreover, some students struggle to translate given problems into their own words

(Zulfa et al., 2024) .Beyond enhancing mathematical problem-solving skills, it is also essential to consider students' learning motivation during the instructional process. Kong and Song (2015) argued that motivation reflects students' enthusiasm and initiative in learning. Increasing motivation is a key principle in achieving learning objectives (Kim, K.J. & Frick, 2011). Therefore, teachers must continuously develop innovative teaching methods to engage students and foster motivation, ultimately improving learning outcomes.

Thus, improvements are needed in the models, strategies, methods, and techniques used to enhance mathematical problem-solving skills, beginning with increasing student learning motivation. Low learning motivation leads to increasingly complex challenges in the learning process. One model that has been shown to enhance student motivation is Project-Based Learning (PjBL). PjBL is a student-centred approach that enables students to actively engage in learning and problem-solving while teachers focus on curriculum design and assessment (Lou, Liu, Shih, & Tseng, 2011). Chiang & Lee (2016) compared to other learning models, PjBL presents a broader range of problems, creating a more contextual and authentic learning experience (Belkacem, 2018). During project-based activities, students engage in tasks such as designing, scheduling, presenting, and evaluating their work. This hands-on involvement increases student motivation, as they are directly engaged in every project stage (Chiang & Lee, .2016)

Students must explore their knowledge when addressing problems to develop satisfactory problem-solving skills. Their ability to solve mathematical problems significantly impacts the accuracy of their solutions. Boaler (2002)argued that regular practice enhances students’ creativity in learning. Geometry is one of the most challenging topics for students due to their limited visualization skills, often resulting in reluctance to engage with the subject (Dockendorff & Solar, 2017). Belkacem (2018) highlighted the role of technology in PJBL as an effective approach for improving problem-solving skills. Among the technologies that support geometry learning are Amazing Geometry Augmented Reality (AGAR) and Assemblr AR, which provide interactive and immersive experiences.

Several studies have explored the use of AR-assisted PjBL. Kristiyanto (2020) investigated the impact of PjBL on improving critical thinking skills and mathematical learning outcomes. Muwahiddah et al (2018) examined problem-solving skills in AR-assisted, ethnomathematics-based PjBL, focusing on students' spatial abilities. Lainufar et al (2020) developed GeoGebra AR-based PjBL learning tools for teaching geometry in junior high schools. However, in these studies, the opportunity for students to practice using AR applications was limited to only two sessions.

Several researchers have investigated the application of the PjBL model assisted by AR. Kristiyanto, (2020) examined the effectiveness of PjBL in enhancing critical thinking skills and mathematical learning outcomes. Similarly, Muwahiddah et al (2018) analyzed students' problem-solving skills through an AR-assisted, ethnomathematics-based PjBL approach, focusing on spatial abilities. Lainufar et al (2020)also developed GeoGebra AR-based PjBL learning tools for teaching geometry in junior high school. However, in these studies, students had only two sessions to practice using the AR application.

Despite these studies, research on AR-assisted PjBL to improve problem-solving skills and student learning motivation remains limited. AR-assisted project activities, such as designing and presenting, have been shown to enhance student motivation and develop mathematical problem-solving skills (Muwahiddah et al, 2018). AR media was integrated throughout the learning process in this study, from the initial stages to the final product, over five sessions. Additionally, AR is easily accessible via certain smartphones, allowing students to engage with the technology by creating and solving problems based on their projects. Given these considerations, this study aims to assess the improvement in students' mathematical problem-solving skills and learning motivation after being taught using the AR-assisted PjBL model. Furthermore, it seeks to determine the interaction between the learning model and students' ability levels to influence these improvements.

Literature Review

Project Based Learning (PjBL)

PjBL is a learning approach centered on challenging problems or fundamental questions that engage students in designing, problem-solving, investigative activities, and independent project work within a predetermined timeframe (Thomas & Ph, 2000). As one of the recommended learning models in the 2013 Curriculum in Indonesia, PjBL encompasses broader and more complex problems than other learning models, as it facilitates contextual and authentic learning experiences(Capraro, R., Capraro, M M., & Moorgan, 2013). These experiences are expected to enhance students' competencies, aligning with the demands of 21st-century learning. Through PjBL, students actively participate in the learning process, enabling them to acquire mathematical knowledge more effectively (Boaler, 2002). Practical activities and conceptual exploration are components of PjBL, as students construct their understanding while working on projects (Bluemenfeld et al., 1991). Consequently, PjBL fosters deeper comprehension of mathematical concepts by encouraging students to actively build their knowledge.

Augmented Reality

Augmented Reality (AR) is an emerging technology with significant potential in the learning process. AR integrates Virtual Reality (VR) with the real world, creating an interactive experience that enhances learning. According to Sunjaya, AR is a technology that enables the integration of three-dimensional virtual objects into the real-world environment in real-time, often incorporating graphic overlays. Thus, AR is a medium that merges virtual elements with the physical world.

Unlike Virtual Reality (VR), which fully immerses users in a simulated environment, AR allows users to interact with 3D virtual objects while maintaining a connection to the real world (Zund et al., 2015). Several AR applications can be utilized in geometry learning, including m-education, Unity 3D 2017, Assemblr, and Geogebra AR. Three key principles characterize AR. First, it combines virtual and real elements. Second, AR operates in real-time. Third, it creates the illusion that virtual objects exist in the real world. In essence, AR enhances the real environment by overlaying virtual objects, making the experience more immersive and interactive for users (Peddi, 2017)

Mathematical Problem Solving

A situation is problematic if it does not conform to the wishes (Ernest, 1991;Ginanti et al., 2017). Montague (2007) defines a mathematical problem-solving process as a complex thinking activity that involves overcoming a problem using certain strategies and processes. A problem can be solved by analyzing the problem, creating a problem-solving strategy, completing the chosen strategy, and then re-examining the problem-solving (Polya, .1975)

Student Learning Motivation

Motivation is the inner strength that drives people to use their power to achieve a goal (Hanus & Fox, 2015). According to Kong and Song (2015), student motivation refers to the passionate nature of students who take the initiative to follow learning and demonstrate their willingness to learn. Koff & Mullis (2011) define student learning motivation as the desire within students to follow learning without coercion.

Method

This research employed a quantitative approach with an experimental research design and a quasi-experiment design. In addition, sampling did not allow researchers to form new groups in which students are randomly selected as pure experiments, resulting in samples drawn from the available classes(J. W.Creswell, 2016). This study consisted of the independent and the dependent variables. The independent variable in this study was the PjBL model assisted by AR, while the dependent variable was the student's mathematical problem-solving skills. The design used was a Pre-test-Post-test Control Group Design.The population in this study were all 8th-grade students of one of the public junior high schools in Banda Aceh, Indonesia. The sample was selected through random sampling. It means all groups have the same opportunity to become experimental classes (Ruseffendi, 1988). The sample size was 131 students, consisting of four classes, with two control and two experimental classes.

This study used two types of instruments: tests and non-tests. The validated questions included pre-test and post-test questions with the same weight and difficulty. The pre-test and post-test were long answer questions about polyhedron, adapted from Muwahiddah (2018). Before the test items were administered, they were validated by two lecturers. A learning motivation questionnaire developed by Arbain and Shukor (2015) was used to assess learning motivation, with a reliability of 0.892 and meet the research objectives.The data was collected using a pre-test and post-test technique. Before learning, the researchers administered a pre-test at the first meeting. The researchers then held five sessions to examine polyhedron taught directly by one of the researchers in both experimental and control classes. A post-test was administered at the end of the meeting.

In this study, the AR APK was used throughout learning, and the outcomes of student projects were also designed in the AR APK. Data was analyzed using one-way ANOVA to determine the improvement in problem-solving skills and student learning motivation. Before performing the ANOVA test, the normality and homogeneity tests were conducted as prerequisites. Furthermore, the interaction between student level and the applied model was analyzed using two-way ANOVA.

Results

Mathematical Problem-Solving Skills

The data collection and analysis of this study focused on problem-solving abilities. The N-Gain test was carried out after data collection for both experimental and control classes. Data on the results of pre-test, post-test, and N-Gain problem-solving skills are presented in Table 1.

Table 1. Data of Mathematical Problem Solving Skills Score of Experimental and Control Class

Ability	Score	Experiment			Control		
		N	$\bar{x}$	SD	N	$\bar{x}$	SD
Mathematical problem solving	Pre-testPre-test	66	34.46	6.1	65	40.38	10.6
	Posttest	66	71.38	8.4	65	60.10	16.2
	N-Gain	66	0.20	0.06	65	0.13	0.08
Ideal Maximum Score = 100							

Table 1 shows that the average scores of the experimental and control classes are similar. The average post-test score of the experimental class is higher than that of the control class. This shows an increase in students' mathematical problem-solving ability after being given treatment. Table 2 presents the descriptive statistics of mathematical problem-solving skills scores based on Initial Mathematical Ability (IMA).

Table 2 presents a comparative analysis of students' mathematical problem-solving skills in experimental and control classes, categorized by IMA. The pre-test results indicate that students with high ability in the experimental and control groups achieved average scores of 59.45 and 56.59, respectively, while those with medium ability scored 41.20 and 38.55. Meanwhile, students with low initial ability recorded pre-test scores of 26.77 in the experimental group and 26.39 in the control group.

Following the intervention, the post-test scores show a substantial improvement across all ability levels. High-ability students in the experimental class attained an average score of 90.06, compared to 79.39 in the control class. Similarly, students in the medium-ability category improved to 71.70 in the experimental group and 57.40 in the control group. The lowest ability group also showed progress, with post-test averages of 50.00 and 38.98 in the experimental and control classes, respectively. The effectiveness of the intervention is further reflected in the normalized gain (N-Gain) scores. The experimental class exhibited a higher average N-Gain across all ability levels, with an overall mean of 1.75, compared to 1.03 the control group. This indicates that students in the experimental class experienced a greater enhancement in their mathematical problem-solving skills compared to their counterparts in the control group, reinforcing the positive impact of the applied treatment.

Table 2. Data of Mathematical Problem Solving Skill Score Based on IMA

KAM	N	Experiment Class					
		Pre-test		Post-test		N-Gain	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
High	12	59.45	5.08	90.06	2.91	0.85	0.73
Medium	41	41.20	6.63	71.70	11.86	0.55	0.22
Low	13	26.77	4.11	50.00	12.72	0.35	0.16
Total	66	127.42	15.82	211.76	27.49	1.75	1.11
		Control Class					
High	14	56.59	4.98	79.39	9.87	0.55	0.19
Medium	40	38.55	4.68	57.40	10.09	0.32	0.16
Low	11	26.39	2.59	38.98	13.86	0.16	0.26
Total	65	121.53	12.25	175.77	33.82	1.03	0.61
Ideal Maximum Score = 100							

Data Analysis of Interaction between Learning Model and Student Level (High, Medium, and Low) on Mathematical Problem Solving Skills

After the prerequisite normality, homogeneity, and N-Gain data groups between the experimental and control classes are completed, an interaction test between the learning model and the student level (high, medium, low) was performed to improve mathematical problem-solving skills.

Table 3. The Interaction between Learning and Student Level on Improvement of Mathematical Problem Solving Skills

Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.263[a]	5	.053	11.594	.000
Intercept	2.532	1	2.532	558.631	.000
Learning	.113	1	.113	24.950	.000
Level	.862	2	.862	0.889	.766
Learning * Level	.003	2	.002	.382	.683
Error	.566	125	.005		
Total	4.464	131			
Corrected Total	.829	130			
a. R Squared = ,317 (Adjusted R Squared = ,290)					

According to Table 3, the analysis findings indicates no interaction between the learning model and the student level (high, medium, or low) in improving students' mathematical problem-solving skills (p=0.683). It signifies that learning model and student level (high, medium, low) do not affect students' mathematical problem-solving skills.

Student Learning Motivation

Learning motivation data were acquired by administering questionnaires to experimental and control classes. The data obtained is ordinal and then converted into interval data using Method Of Successive Interval *(*MSI)

Table 4. Description of Student Learning Motivation Data

Class	Test	$\overline{x}$	N-Gain	Average	Criteria
Experiment	Pre-test	83.18	8.02	0.12	Low
	Post-test	94.04			
Control	Pretest	81. 97	4.90	0.07	Low
	Post-test	88.51			

Table 4 presents a comparative analysis of student learning motivation in the experimental and control classes before and after the learning intervention. The pre-test results indicate that the average motivation score in the experimental class was 83.18, slightly higher than the control class, which recorded an average of 81.97. Following the intervention, both groups demonstrated increased motivation, with post-test scores rising to 94.04 in the experimental class and 88.51 in the control class.

Furthermore, the normalized gain (N-Gain) scores highlight the extent of improvement in student motivation. The experimental class achieved an N-Gain of 8.02, while the control class recorded a lower gain of 4.90, reflecting a difference of 3.12 points. These findings suggest that students in the experimental class experienced a more substantial enhancement in their learning motivation than those in the control class, reinforcing the positive impact of the applied instructional approach.

Interaction between Learning Model and Student Level (High, Medium, and Low) on Student Learning Motivation

After determining that the N-Gain data groups of experimental and control classes are normally distributed with homogeneous data variance, a two-way ANOVA test is conducted using SPSS version 16.0 to determine the interaction between the learning model and student level (high, medium, low) on student learning motivation. The results of the interaction analysis are presented in Table 5. The table shows that the analysis results indicate no effect between the learning model and student level (high, medium, low) on student learning motivation (p=0.95). Hence, it can be concluded that there is no interaction between the learning model and student level (high, medium, low) on student learning motivation.

Table 5. Test Results of Interaction between Learning and Student Level on Improvement of Student Learning Motivation

Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.039[a]	5	.008	1.564	.175
Intercept	.665	1	.665	133.816	.000
Level	.013	2	.007	1.315	.272
Learning	.009	1	.009	1.795	.183
Level * Learning	.024	2	.012	2.401	.095
Error	.616	124	.005		
Total	1.491	130			
Corrected Total	.655	129			

a. R Squared = .059 (Adjusted R Squared = .021)

Discussion

Mathematical Problem Solving

Based on the data analysis, the statistical analysis and hypothesis tests indicate a significant improvement in the experimental class taught using the PjBL model assisted by AR compared to the control class, which was taught using the PjBL model without AR. The average N-Gain value falls within the medium category. This outcome is attributed to the limited availability of smartphones, with only seven units shared among 35 students. To fully implement AR-assisted PjBL learning, a minimum of 15 smartphone units should be available.

The PjBL model follows a structured sequence of learning activities to equip students with problem-solving skills. The effectiveness of the AR-assisted PjBL model stems from its ability to foster student autonomy throughout the learning process. One of the notable feature of PjBL is independent learning (Hogue, 2024). It begins with fundamental problems that guide students toward project-based tasks and culminates in the presentation of their final products, thereby enhancing their problem-solving skills. Moreover, integrating AR technology allows students to better comprehend polyhedra through interactive visualizations while increasing their engagement with the learning materials.

Overall, the experimental class demonstrated superior mathematical problem-solving skills compared to the control class. In the PjBL model without AR, teachers relied on improvised tools for project work. Conversely, in the AR-assisted PjBL model, teachers utilized AR applications (APKs) to facilitate project-based learning. This approach enhanced time efficiency and made the learning process more engaging, enjoyable, and meaningful.

This finding is consistent with previous studies, indicating that technology-assisted PjBL actively engages students in information-seeking activities, enabling them to solve problems independently and through group discussions. This result aligns with the perspective of Chuan and Yang (2013), who asserted that applying the PjBL model in learning can enhance students' mathematical problem-solving skills. Similarly, other research suggested that engaging in in-depth investigative activities strengthens students' ability to address challenges (Fajarwati et al., 2017). A study in Saudi Arabia by Alenezi, (2023) also conforms the finding of this study, revealing that PjBL contributes to better mathematical problem solving skills among secondary students. Similarly, a study by Karan & Brown (2022) agreed with the finding. However, the latter study was conducted in higher education setting.

This study also examined the aspect of interaction. Ruseffendi (1988)noted that variations in the dependent variable significantly correspond to changes in the independent variable, emphasizing the potential for improvement through instructional interventions. Accordingly, this research explored the correlation between learning factors, student levels, and students' mathematical problem-solving skills. The analysis revealed no interaction effect between the learning model and students' proficiency levels (high, medium, or low) on their mathematical problem-solving ability. This suggests that the improvement in students' problem-solving skills is influenced solely by the AR-assisted PjBL model. The structured steps of the PjBL approach train students to effectively engage in problem-solving tasks.

The rapid advancement of technology is expected to enhance the learning process. Geometry is often challenging for students due to its abstract nature; therefore, integrating technology into learning can help address these difficulties by providing a more concrete representation of abstract geometric concepts through AR. AR media transforms 2D images into 3D visualizations, making geometric objects appear more tangible. Zund et al. (2015)concluded that experimental approaches and the incorporation of technology can facilitate students' comprehension of mathematical concepts by making abstract objects appear realistic. Similarly, Rohendi et al. (2018) found that AR applications on Android platforms significantly aid students in understanding three-dimensional and diagonal geometry concepts. Findings from previous research on AR media suggest that its use can enhance students' understanding of mathematical concepts while improving their ability to visualize geometric structures. Consequently, incorporating AR into classroom learning will strengthen students' visualization skills and mathematical comprehension.

Student Learning Motivation

The class utilizing the AR-assisted PjBL model demonstrates a higher N-gain value compared to the class that does not incorporate AR. The average N-gain value in the experimental class is 0.34, which falls within the medium category, while the average N-gain value in the control class is 0.26, categorized as low. This study also examined the interaction between instructional methods and students' initial proficiency levels in relation to learning motivation. Based on the analysis, no significant interaction is found between the learning model and students' proficiency levels (high, medium, or low) in influencing learning motivation.

The analysis of the interaction between instructional methods and student proficiency levels in relation to motivation indicates that the AR-assisted PjBL model positively influences student motivation. These findings align with those of Purnamasari (2014), who reported no significant interaction between learning models and student groupings in determining learning motivation. Similarly, research conducted by (Jumaisyaroh & Hasratuddin (2015)found no interaction between instructional methods and students' initial mathematical abilities in enhancing learning motivation.

Conclusion

Based on the analysis and discussion, PjBL model assisted by AR is more effective in enhancing students' mathematical problem-solving skills and learning motivation than the PjBL model without AR. Furthermore, no significant interaction is observed between the learning model and students' proficiency levels (high, medium, or low) in improving mathematical problem-solving skills and learning motivation.

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